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Compensatory responses and reflex mechanisms in postural tongue control

Takayuki Ito^{1,2}, Andrew Sazbados¹, Jean-Loup Caillet¹, Pascal Perrier¹.

1: GIPSA-lab, CNRS, Grenoble INP, Univ. Grenoble Alpes, 2: Haskins Laboratories.

takayuki.ito@gipsa-lab.grenoble-inp.fr



Introduction

The tongue is a fundamental organ in basic biological human functions, such as breathing, swallowing and speaking. However, the neurophysiological mechanisms for fine tongue motor control have not been investigated thoroughly.

Whereas many studies of postural limb control have documented the role of reflex mechanisms in rapid compensation for perturbations, it is still unclear whether such low-level control mechanisms exist in the tongue.

The study addressed this question by examining tongue responses to transient mechanical perturbations using a combination of behavioral observations and computational simulations with a biophysiological tongue model.

Method

Behavioral experiment

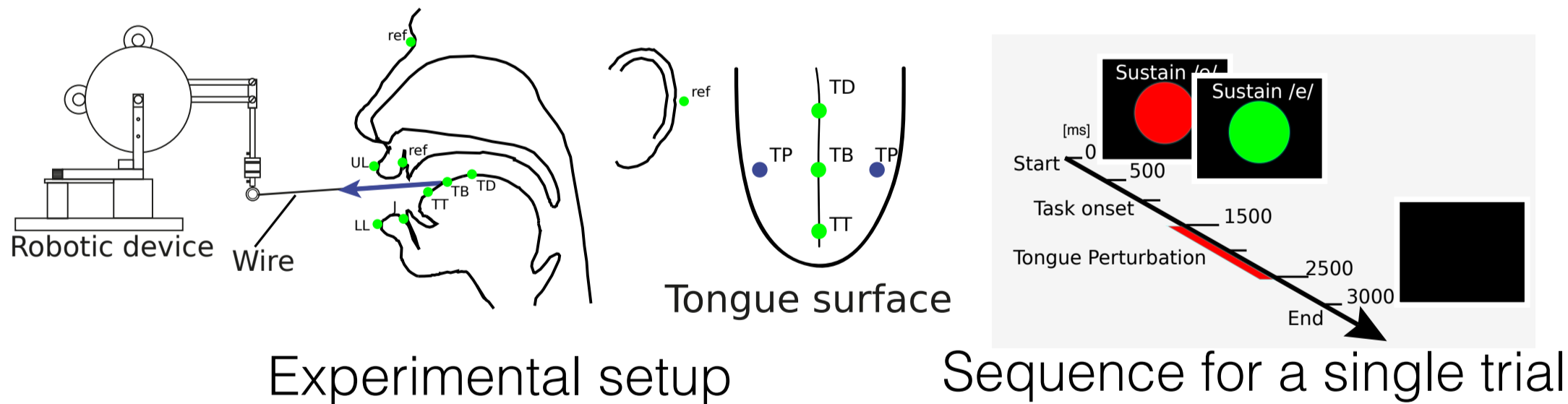
Participants: 8 native speakers of French.

Task: Combination of the following vowels and manners.

(1) Vowel: /i/, /e/ and /ε/.

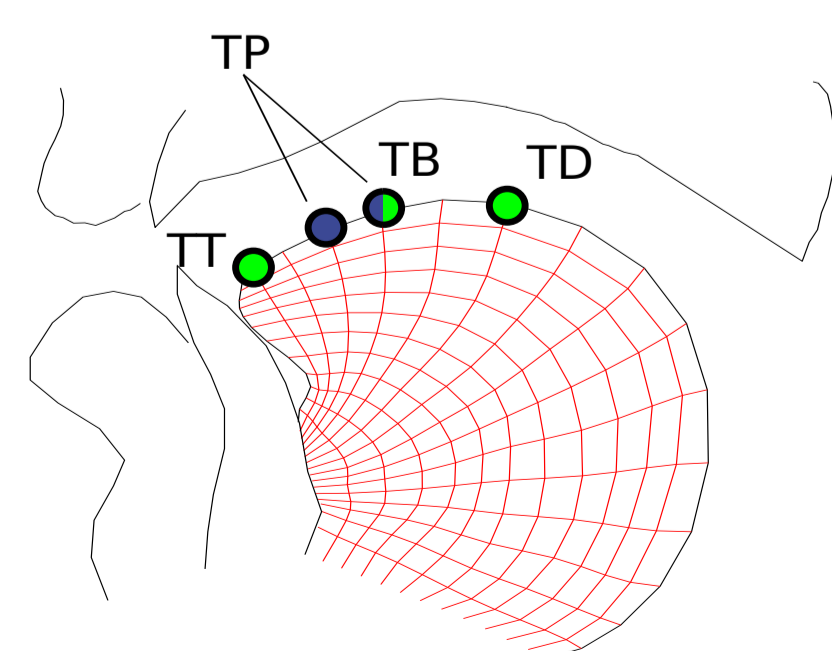
(2) Manner: Voicing, Whispering and Posturing

Tongue perturbation: 1 N of step-wise force.



Mathematical simulation

Biomechanical model (Perrier et al. 2003)



2D Finite element model

221 nodes connected by viscoelastic elements

Muscle force model (λ -model):

$$F(t) = \rho(e^{c(L_e - \lambda) + c_{ref}(L - L_e)} - 1)$$

ρ : gain by muscle size/composition

c : activation gain

c_{ref} : reflex gain

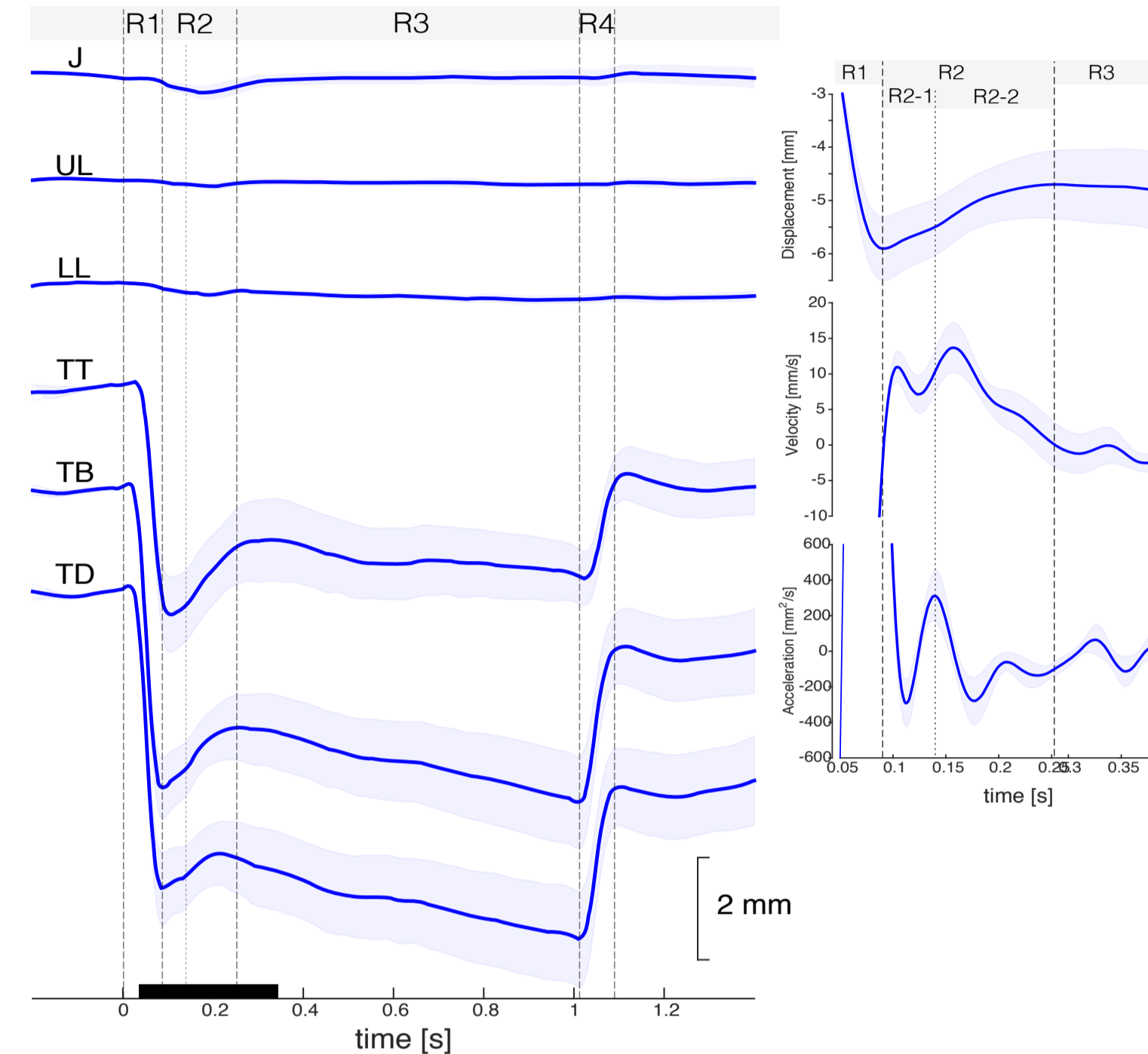
λ : threshold length for activation

L : current muscle length

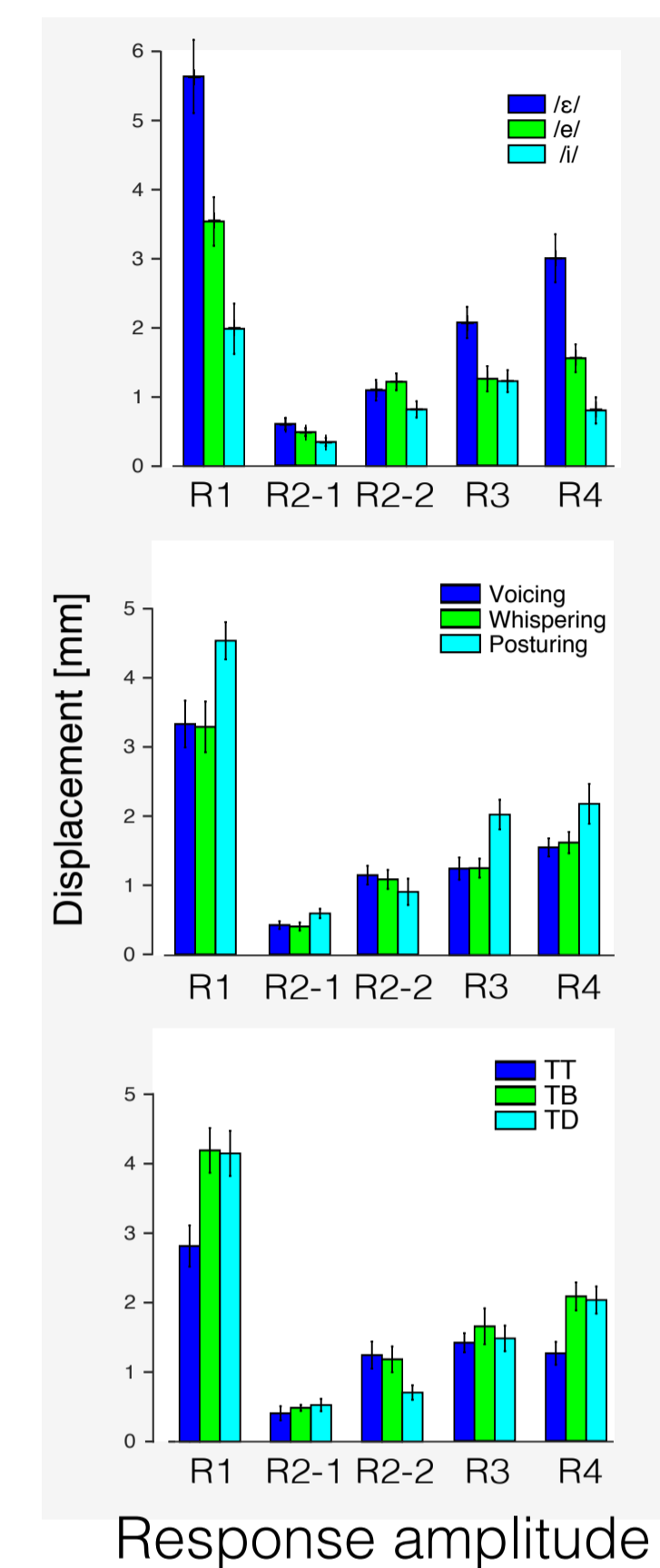
L_e : muscle length for the vowel /e/

Results

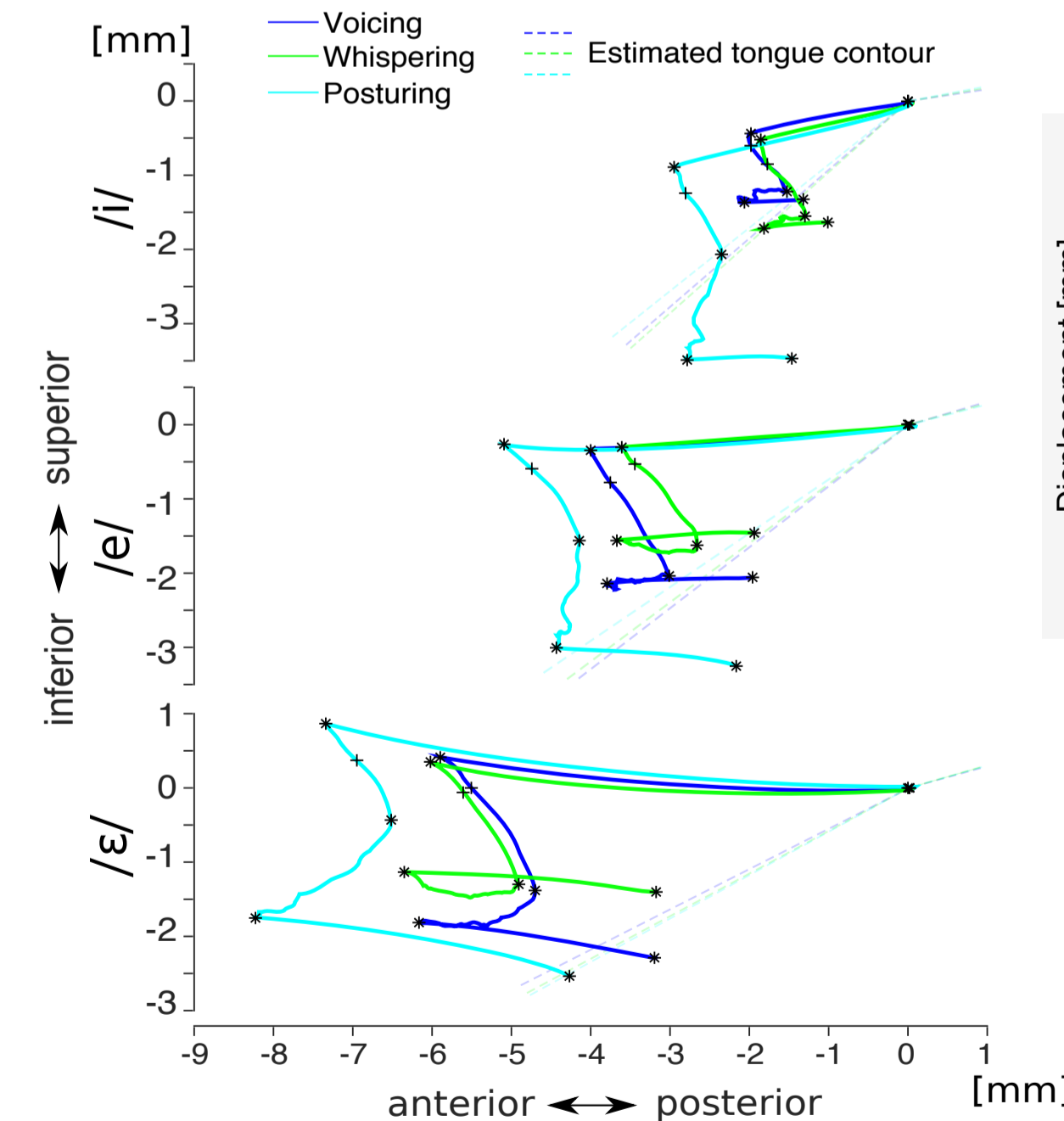
Recorded movements



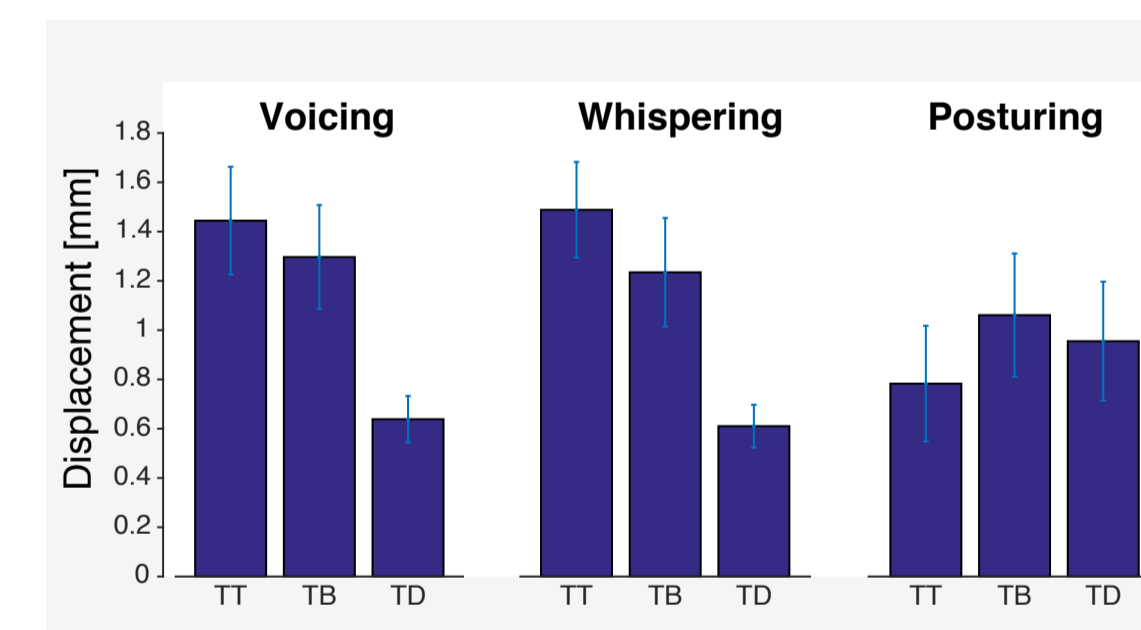
Horizontal displacements



Response amplitude

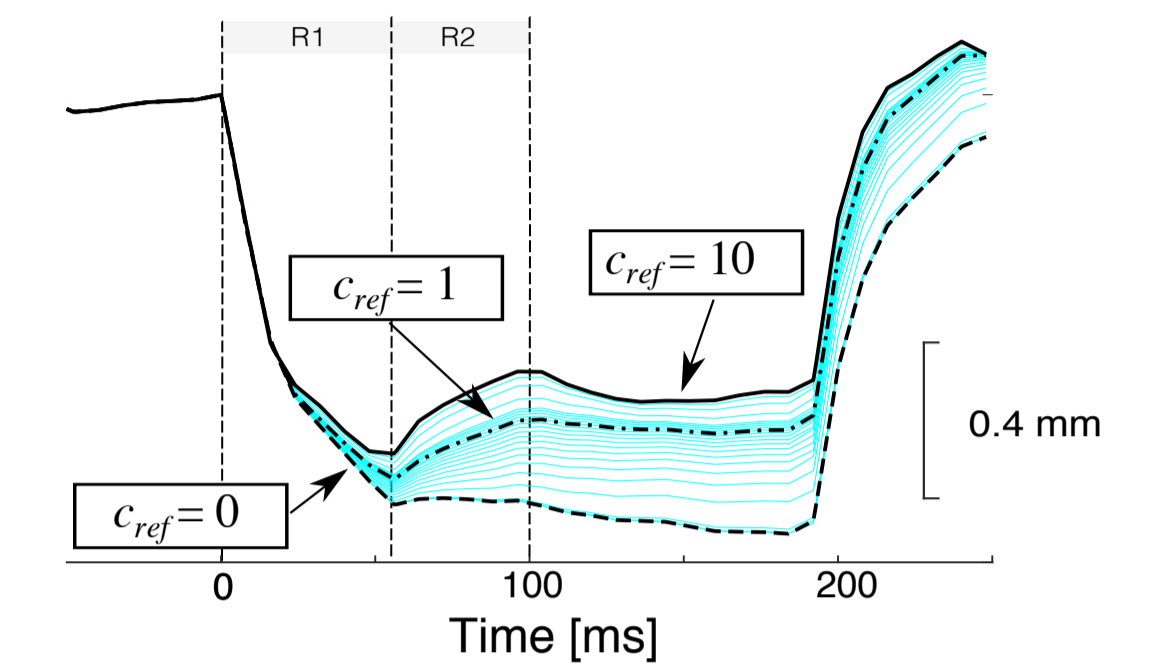


Displacement of TB in sagittal plane

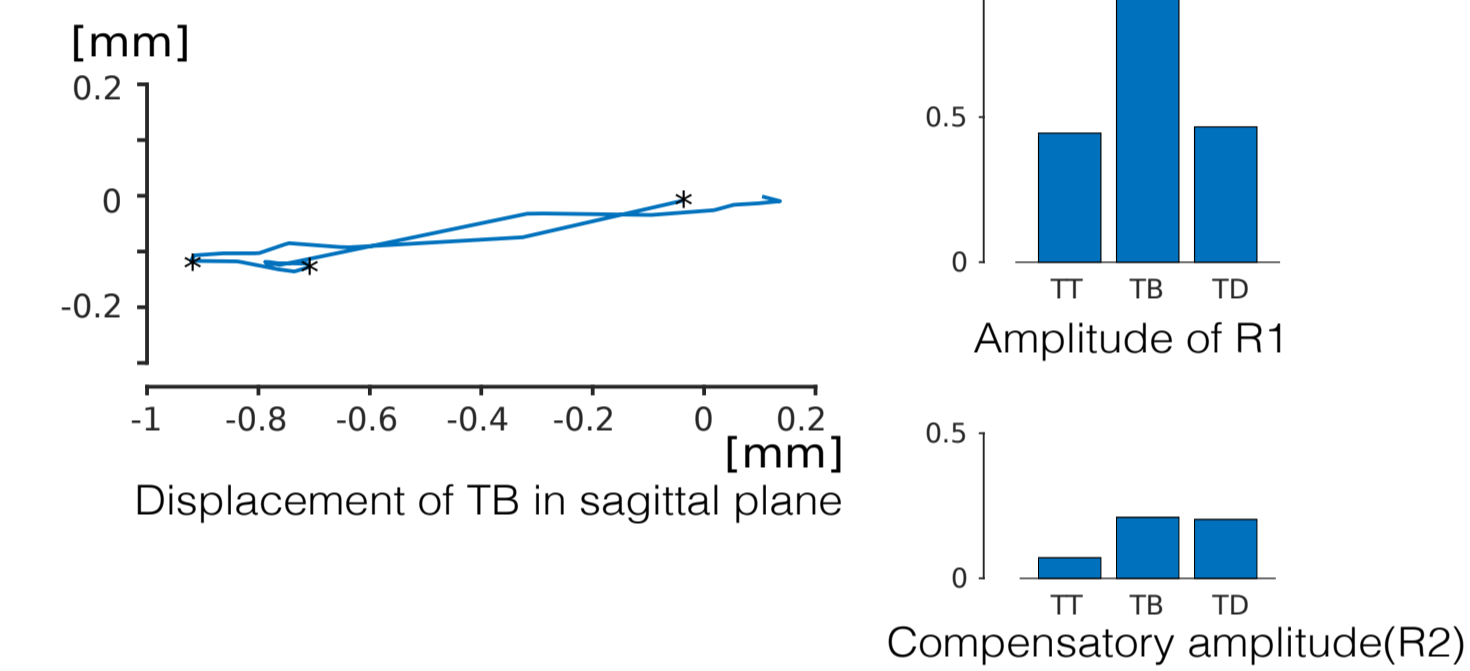


Compensatory amplitude (R2-2)

Simulated movements



Response changes by reflex gain (TB)



(1) The reflex mechanism in the model reproduced the compensatory response observed in the recorded movements.

(2) The amplitudes of the compensatory responses (R2-2) in each site of tongue surface were modulated depending on the speaking manners in the task [$F_{(4,182)} = 8.33, p < .001$]. The simulated change in the sites of tongue surface was similar to the change in Posturing condition.

(3) Initial displacement changes (R1) varied depending on the sites of tongue surface [$F_{(2,182)} = 26.22, p < .001$]. The simulation failed to reproduce the similar variation across the tongue sites, suggesting that the tongue may not have isotropic mechanical property in the body.

Summary

(1) We demonstrated a quick compensatory response of the tongue, which may be driven by reflex mechanism, that was modulated in a task-dependent manner.

(2) Tongue control in speech may be organized to preserve auditorily relevant properties of the vocal tract geometry via rapid feedback mechanisms including muscle mechanics and reflex.

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